A Novel Calculation of Priming Volume and Required Packed Cell Transfusion to Maintain Optimal Haematocrit During Cardiopulmonary Bypass

B. Karthikeyan[1], R. Vijay Anand[2], Meenakshi Sundaram[3], K.J. Vigneswaran[1], A. Rathinavel[4]

ABSTRACT

Introduction: Hemodilution during cardiopulmonary bypass is an acceptable method to avoid the complications of continuous flow at the microcirculatory level. Hemodilutional anemia during cardiopulmonary bypass can lead to inadequate oxygen delivery and, which may result in ischemic organ injury to all the organs especially to the brain, kidney, lungs and liver. Study aimed to investigate the effectiveness of a novel formula for calculating priming volume (PV) and required packed cell (PC) volume to maintain optimal hematocrit level during cardiopulmonary bypass.

Material and methods: This Prospective interventional study was done on 150 patients who underwent open-heart surgeries in our Institute from January 2018 to December 2018. Group A-75 patients: perfusionist's old protocol for calculating priming volume and required packed cell volume calculation and the nadir hematocrit (Hct) during CPB and postoperative outcome monitored. Group B- 75 patients: customized novel formula was applied for calculating PV and required PC volume and the nadir Hct during CPB and postoperative outcome monitored and both the groups compared.

Results: In our study results showed that maintaining optimal Hct of 25% (>20%) in adult and 30% (>25%) by using our novel customized formula for calculating prime volume and required packed cell volume was significantly improved the nadir Hct from 19.16% to 21.8% as well as average Hct values from 19.7% to 23.4%. Complications of Hemodilution were significantly reduced in the study Group B. Mortality was reduced to 2.7% from 5.3%. Respiratory complication like reintubation rate and nonfatal noncardiogenic pulmonary edema rates reduced from 34.7% to 17%. Coagulopathy with postoperative blood products requirement reduced from 20% to 7%.

Conclusion: Our Study showed that application of this novel formula is very useful and easy for both the perfusionists and the surgeons in maintaining optimal Hct during CPB thereby improving the postoperative results following open heart surgeries.

Keywords: Hemodilution, Cardiopulmonary bypass, Optimal Hematocrit, Open Heart Surgeries, Priming Volume, Required Packed Cell Volume.

INTRODUCTION

Hemodilution during cardiopulmonary bypass is an acceptable method to avoid the complications of continuous flow at microcirculatory level. Hemodilutional anemia during cardiopulmonary bypass can lead to inadequate oxygen delivery and, which may result in ischemic organ injury to all the organs especially to the brain, kidney, lungs and liver. In cardiopulmonary bypass (CPB), the nadir hematocrit (Lowest level of Hct) can vary widely with body size and pre-bypass hematocrit variations, yet its effects on perioperative organ dysfunction and patient outcomes remain largely unknown.

The Boston group[1] headed by Jonas recently demonstrated, in an intravital animal model, that perfusion of the cerebral microcirculation is not impaired by high hematocrit value (30%) during cardiopulmonary bypass (CPB) compared with moderate (20%) or low (10%) hematocrit value. They also reported evidence of increasingly inadequate cerebral tissue oxygenation and greater white cell–endothelial activation as hematocrit values during CPB decreased.[1] Finally, the authors proposed that their intravital results of increased ischemia and inflammatory tissue injury with greater hemodilution explained earlier findings of improved neurological outcomes with high hematocrit.[2,3]

Arguably, the above results may have significant implications to current CPB practice as they contradict prevailing cardiac surgical dogma and current recommendations of textbooks[4,5], that is, that lower hematocrit values (20%) minimize microcirculatory disturbances during CPB and hence will improve tissue perfusion and oxygen delivery.

Additionally, if these findings in the cerebral microcirculation prevail in other capillary beds, then milder Hemodilution may similarly lead to improved post-CPB outcomes of other vital organs.

In adult CPB, variations of body size and pre-CPB hematocrit, coupled with the essentially constant bypass circuit volume,

[1]Senior Resident, Department of Cardiovascular and Thoracic Surgery, Madurai Medical College, Madurai, [2]Associate professor, Department of Cardiovascular and Thoracic Surgery, Madurai Medical College, Madurai, [3]Senior Assistant professor, Department of Cardiovascular and Thoracic Surgery, Madurai Medical College, Madurai, [4]Professor and HOD, Department of Cardiovascular and Thoracic Surgery, Madurai Medical College, Madurai.

Corresponding author: Dr. R. Vijay Anand, Associate Professor, Department of Cardiovascular and Thoracic Surgery, Madurai Medical College, Madurai

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inevitably lead to wide interpatient variability of the nadir on-pump hematocrit.[6]

Study aimed to record the effectiveness of a novel formula for calculating priming volume (PV) and required packed cell (PC) volume to maintain optimal hematocrit level during cardiopulmonary bypass.

MATERIAL AND METHODS

This prospective interventional study was done on 150 patients who underwent open-heart surgeries in our Institute from January 2018 to December 2018. First 6 months of the study period (Group –A-75 patients) we have used our perfusionist's old protocol for calculating priming volume and required packed cell volume calculation and the nadir hematocrit (Hct) during CPB and postoperative outcome monitored.

The old protocol is to start with a fixed priming volume of 1000 to 1500 ml of normal saline solution and 200 to 300 ml of Isolyte M for the cardioplegia preparation. One unit of the packed cell with 250 ml volume added in the priming volume for pediatric cases less than 20 kg weight (or less than 12 years of age). After starting CPB and first cardioplegia administration, Arterial blood gas (ABG) Analysis done for correction of acid-base and electrolyte disturbances. The packed cell will be added only if the Hct goes below 15% otherwise no Hct correction done during CPB.

Last 6 months of the study (Group – B 75 patients) our customized novel formula applied for calculating PV and required PC volume and the Hct during CPB and postoperative outcome monitored and both the groups compared.

The formula for calculating the priming volume is given below. This formula was customized from the fact that Red Blood cell mass will not be changed only the Hct Value will decrease when we add plain fluids like normal saline or isolyte M to the priming volume along with the patient's blood volume. The perfusionist was instructed to calculate the priming volume according to the below formula and restrict the total priming volume within the calculated amount. If in case the calculated volume is less than the priming volume needed to de-air the CPB circuit then he has to add packed cell only for the additional required volume.

After starting CPB, ABG analysis did the Hct monitored. The perfusionist was advised to maintain a Hct of 25% in adult and 30% for paediatric cases (figure-1,2). If the Hct is low then the target Hct then he was advised to use the following formula for calculating the required packed cell volume and then adding it to the reservoir. Hct checked for every one hour till the end of surgery and then nadir Hct noted for all cases and postoperative outcomes monitored for all cases and compared with the previous group of patients. All the data are analyzed and compared using student T-test.

RESULTS

Among the 150 study population total of 36 pediatric patients (24%) and 114 adult patients (76%) were included. In Group A 26.7% of the study population belongs to the pediatric age group and 73.3% belongs to the adult age group. In Group B 21.3% of the study population belongs to the pediatric age group and 78.7% belongs to the adult age group (Table-1).

In Group A 40% (30 patients) were adult males and 46.7% were females. Whereas in Group A 36% (27 patients) were adult males and 54.7% (41 patients) were adult females. In Group A 4% (3 patients) were male children and 9.3% (7 patients) were female children whereas in Group B 5.3% (4 patients) were male children and 4% (3 patients) were female children (Table-2).

Ostium Secundum type (ASD-0S) Atrial septal defect. Pericardial patch closure (PPC) contributes the majority of congenital heart disease surgeries done with 65% (13 cases) in Group A and 50% (8 cases) in Group B (Table-3).

Mitral valve replacement (MVR) contributes majority of acquired heart disease surgeries done with 49% (27 cases) in Group A and 55% (33 cases) in Group B followed by ON

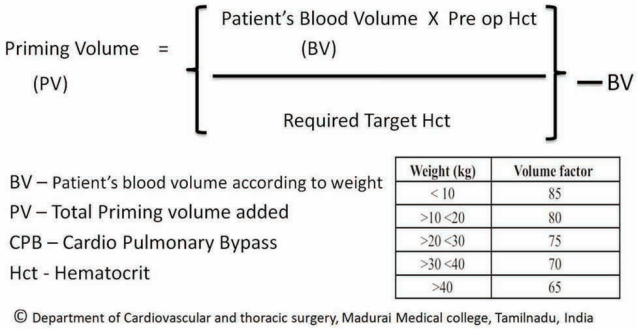

Figure-1: The formula for calculating priming volume.

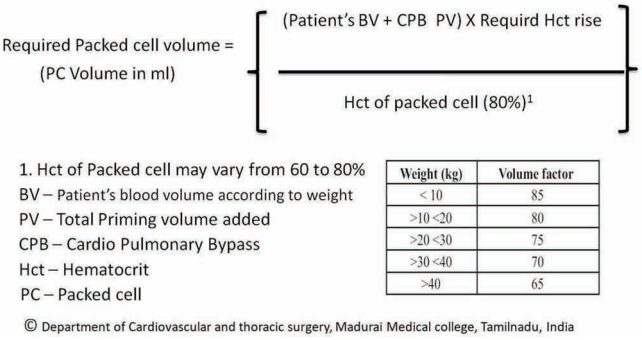

Figure-2: The formula for calculating Required packed cell volume to maintain target Hct.

Age group	Group A	Group B	Total
< 12 years	20 (26.7%)	16 (21.3%)	36 (24%)
Adults	55 (73.3%)	59 (78.7%)	114 (76%)
Total	75	75	150

Table-1: Age-wise Distribution of Study patients

Gender	Group A	Group B	Total
Adult Male	30 (40%)	27 (36%)	57 (38%)
Adult Female	35 (46.7%)	41(54.7%)	76 (50.7%)
Male child	3 (4%)	4 (5.3%)	7 (4.7%)
Female child	7 (9.3)	3 (4%)	10 (6.6%)
Total	75	75	150

Table-2: Sex wise Distribution of Study patients

Procedure	Group A					Group B				
	Adult male	Adult female	Male Child	Female child	Total	Adult male	Adult female	Male child	Female child	Total
Ostium secundum type (ASD-0S) Atrial septal defect. Pericardial patch closure (PPC)	1	7	1	4	13 (65%)	1	4	2	1	8 (50%)
Sinus venosus type ASD-PPC	0	0	0	1	1	1	0	0	1	2
Ventricular septal Defect (VSD)-PPC	1	1	0	2	3	2	0	0	0	2
Atrio ventricular canal defect (AVCD-VSD)- Intra Cardiac repair (ICR)	0	0	1	0	1	0	0	0	0	0
Tetrology of Fallot	0	0	1	0	1	0	0	0	0	0
Double chambered right ventricle DCRV-VSD-ICR	0	0	0	0	0	0	0	1	0	1
Double outlet right ventricle DORV-VSD-ICR	0	0	0	0	0	0	1	0	0	1
Supra cardiac TAPVC-Total anomolus pulmonary venous connection-ICR	0	0	0	0	0	0	0	0	1	1
Sub mitral aneurysm (SMA) – ICR with Mitral valve replacement	0	0	0	0	0	0	1	0	0	1
Total	2	8	3	7	20	4	6	3	3	16

Table-3: Surgical Procedure wise Distribution of Study patients – congenital heart disease

Procedure	Group A					Group B				
	Adult male	Adult female	Male child	Female child	Total	Adult male	Adult female	Male child	Female child	Total
Mitral valve replacement (MVR)	8	19	0	0	27(49%)	7	26	0	0	33(55%)
Aortic valve replacement (AVR)	2	3	0	0	5(9%)	1	2	0	0	3(5%)
Double valve replacement (DVR)	4	2	0	0	6(10%)	4	2	0	0	6(10%)
ON pump Coronary Artery Bypass Graft surgery (CABG)	12	1	0	0	13(23%)	10	0	0	0	10(17%)
MVR + CABG	0	1	0	0	1	0	0	0	0	0
Excision of left atrial myxoma with PPC	0	1	0	0	1	0	1	0	0	1
Pulmonary Thrombo End-arterectomy (PTE)	1	0	0	0	1	0	0	0	0	0
Cardiac transplantation	1	0	0	0	1	0	0	0	0	0
MVR + Tricuspid valve repair	0	0	0	0	0	0	2	0	0	2
Open pericardectomy	0	0	0	0	0	0	1	0	0	1
Hypertrophic Obstructive Cardiomyopathy (HOCM)-Extended septal myectomy	0	0	0	0	0	1	0	0	0	1
Mitral valve repair	0	0	0	0	0	0	1	1	0	2
Total	28	27	0	0	55	23	25	1	0	59

Table-4: Surgical Procedure wise Distribution of Study patients – Acquired heart disease

pump Coronary Artery Bypass Graft surgery (CABG) with 23% (13 cases) in Group A and 17% (10 cases) in Group B (Table - 4).

In Group A 27% (20 cases) of surgeries done for congenital heart diseases and 73% (55 cases) done for acquired heart diseases whereas in Group B 21.3% (16 cases) of surgeries

Procedure	Group A					Group B				
	Adult male	Adult female	Male child	Female child	Total	Adult male	Adult female	Male Child	Female child	Total
Congenital heart surgeries	2	8	3	7	20(27%)	4	6	3	3	16 (21.3%)
Acquired heart surgeries	28	27	0	0	55(73%)	23	25	1	0	59 (78.7%)
Total	30	35	3	7	75	27	31	4	3	75

Table-5: Surgical Procedure wise Distribution of Study patients- both congenital and acquired

Variables	Group A	Group B
NADIR HCT (Average)	19.16%	21.8%
Average HCT during CPB	19.76%	23.4%
NADIR HCT (in mortality cases)	19.75%	19%
Average HCT (in mortality cases)	19.9%	21%
NADIR HCT (in patients with post op complications)	17.75%	17.8%
Average HCT (in patients with post op complications)	19%	19.8%
Average packed cell transfusion on CPB (ml)	67	227

Table-6: Nadir and average Hematocrit values

Postoperative outcome and complications	Group A (75 cases)	%	Group B (75 cases)	%
Mortality	4	5.33	2	2.7
Duration of ventilation (hours- average)	25.17		19.77	
ICU stay in days- average	3.5		2	
Average drain on day 0	409.2ml		240 ml	
Reintubation	6	8	2	2.7
Pulmonary edema	26	34.7	13	17
Renal dysfunction and failure	2	2.7	1	1.3
Low cardiac output state	5	6.7	3	4
Stroke/Cerebro vascular accidents	2	2.7	1	1.3
Coagulopathy/Disseminated intravascular coagulation	15	20	6	8
Others	8	10.7	2	2.7

Table-7: Comparison of postoperative outcomes

Arterial blood lactate levels (mmol/L)	Baseline	CPB- Onset	CPB- 1 hour	CPB- 2 hours	ICU arrival
Group A	0.8	1.2	8.2	11	10.4
Group B	0.8	1.2	5.1	7.2	6.0

Table-8: Comparison of lactate values

done for congenital heart diseases and78.7% (59 cases) done for acquired heart diseases (Table-5).

Average of Nadir HCT (lowest level of Hct recorded during CPB) in Group A is 19.16% whereas it is 21.8% in Group B. Hct was maintained an average of 19.76% in Group A and 23.4% in Group B which is significantly higher. Both the nadir and average Hct was significantly lower in patients who died in the postoperative period as well as patients who developed postoperative complications. The average packed cell transfusion rate is 67 ml only in Group A whereas it was significantly increased in Group A to 227 ml to achieve the optimal Hct (Table-6).

Totally 4 patients died in Group A which is 5.33% and the mortality is 2.7% in Group B. Respiratory complications like reintubation rate 8% in Group A whereas 2.7% in Group B. Non fatal non cardiogenic pulmonary edema rate is 34.7% in Group A whereas 17% in Group B. Coagulopathy with bleeding rate was higher in Group A around 20% whereas it was 8% in Group B (Table-7).

Lactate is one of the markers of tissue perfusion during cardiopulmonary bypass. Group B showed a significant reduction in the lactate value at CPB one hour with 3.1 mmol/l reduction, 3.8 mmol/L reduction at 2 hours and 4.4 mmol/L reduction at ICU arrival (table-8).

DISCUSSION

We have demonstrated, via this prospective cardiac surgery series, that adverse outcomes after CPB are systematically increased as a function of hemodilution severity. Specifically, we showed that most major complications, including reintubation rate, pulmonary edema, Coagulopathy and mortality are increased as the nadir hematocrit during CPB decreased.

Moreover, this hematocrit–complications association inevitably resulted in significantly and systematically greater

intensive care requirements, hospital stays, and death with increasing levels of hemodilution, particularly for the lowest hematocrit value less than 20%. Lowest hematocrit value (%) was also found to be an independent predictor of operative mortality and morbidity.

Other authors[9-11] have suggested a possible link between hemodilution on CPB and worse operative outcomes after CPB. Hemodilution during CPB results from the mixing of pump crystalloid and colloid prime solution with the patient's blood, and these two relative volumes, along with pre-CPB hematocrit, will largely determine the nadir hematocrit. In that sense, the lowest hematocrit value during CPB is then a potentially modifiable risk factor.

Changes to several areas of practice in CPB patients can alter the extent of hemodilution experienced in a given patient. These include controlling preoperative blood loss during routine phlebotomy and cardiac catheterization; possible redesign and use of variable-size, or multiple sizes of, CPB circuits to be used according to patient BSA; minimizing of the tubing size (length and diameter) connecting the patient and pump; more timely return of collected cells to the circulating volumes; more strict control of intraoperative blood loss and fluid administration; use of retrograde autologous priming of the CPB circuit, which has been shown to reduce hemodilution and transfusion requirement[16,17]; and, lastly, freer use of blood transfusions during CPB so as to maintain hematocrit at predetermined levels. The latter is perhaps the most controversial of the above recommendations.

By applying our new formula for prime volume calculation and required packed cell volume to maintain optimal hematocrit, the number of packed cell transfusions during CPB increased significantly. The average packed cell transfusion rate is 67 ml only in Group A whereas it was significantly increased in Group A to 227 ml to achieve the optimal Hct. (Table 6). However, the postoperative outcomes like mortality, respiratory complications and Coagulopathy were significantly reduced in Group B which is correlating with increased nadir as well as average Hct maintained during CPB by using the new formula. This is also correlated with a significant reduction of lactate values at CPB one hour with 3.1 mmol/l reduction, 3.8 mmol/L reduction at 2 hours and 4.4 mmol/L reduction at ICU arrival

CONCLUSION

We conclude that maintaining optimal Hct of 25% (>20%) in adult and 30% (>25%) by using our novel customized formula for calculating prime volume and required packed cell volume was significantly improved the nadir Hct from 19.16% to 21.8% as well as average Hct values from 19.7% to 23.4%. Complications of Hemodilution were significantly reduced in the study Group B. Mortality was reduced to 2.7% from 5.3%. Respiratory complication like reintubation rate and nonfatal noncardiogenic pulmonary edema rates reduced from 34.7% to 17%. Coagulopathy with postoperative blood products requirement reduced from 20% to 7%. Optimal use of packed cells during CPB as per the calculation to maintain optimal Hct will significantly improve the post operative outcomes as shown in our study. Our Study proved that, application of this novel formula is very useful and easy for both the perfusionists and the surgeons in maintaining optimal Hct during CPB thereby improving the post operative results following open heart surgeries.

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